Making Use of Turbulence and its Interaction with Sound: A Non-Invasive Flow Monitor

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Extended Abstract

Natural river systems and urban drainage infrastructure are becoming more frequently overloaded by heavy flows. Rising urbanization is bypassing the natural infiltration processes, while increasing population is demanding a greater capacity from our flow conduits. Additional loading is being generated by climate change, with the UK Meteorological Office predicting significantly greater peak flows over the next 80 years.

Flow properties and conduit conditions must be monitored more effectively in order to minimise failures through pro-active maintenance and real-time control, but the best technologies at present are too invasive, too costly for mass deployment, and require regular maintenance.

Flowing water exhibits a unique surface pattern driven by the flow induced turbulence. This pattern appears to be a function of the underlying flow properties. In this project, an airborne acoustic sensor is developed which is capable of remotely characterizing the free surface pattern of shallow flows. Using this device it is possible to track to the pattern to obtain a velocity measurement, but also to analyse the spatial properties of the pattern in order to infer additional flow information such as hydraulic roughness, turbulence scale, and sediment properties.

A field version of the device was constructed and trialled in a foul sewer pipe in order to test the ability to measure velocity and flow depth, while a more precise laboratory version was developed in order to investigate the additional information contained within shallow flow surfaces.

A basic schematic is shown in figure 1.1. An ultrasonic signal is reflected from the water surface and received at an array of microphones. The phase of the signal received at a given microphone is directly related to the surface fluctuations at the point of specular reflection. By tracking the surface features as they move beneath the microphone array, it is possible to quantify the translation velocity. Using time-of-flight it is also possible to determine flow depth. This has been conducted in a field environment to an accuracy of 8%.

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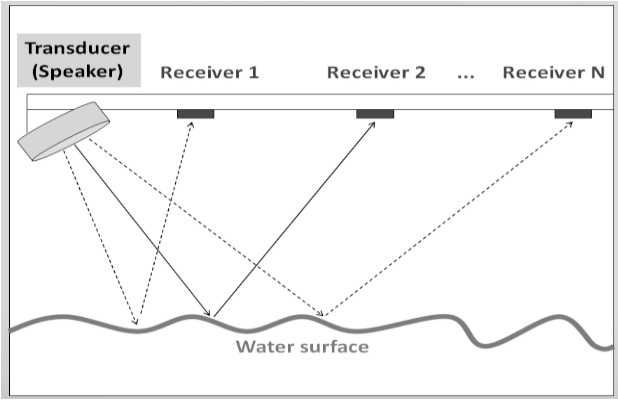

Fig. 1.1 Source-receiver geometry

Further work investigates the information contained in the surface pattern itself. It can be observed that the roughness pattern evolves gradually as it travels downstream. This evolution in surface pattern may be quantified from the surface fluctuation data obtained at multiple locations on the flow surface using the acoustic device. The dependence of the correlation upon the spatial separation follows an oscillatory relationship. This is known as the spatial correlation function (SCF). Examples of this are shown in Fig. 1.4 for three arbitrary regimes.

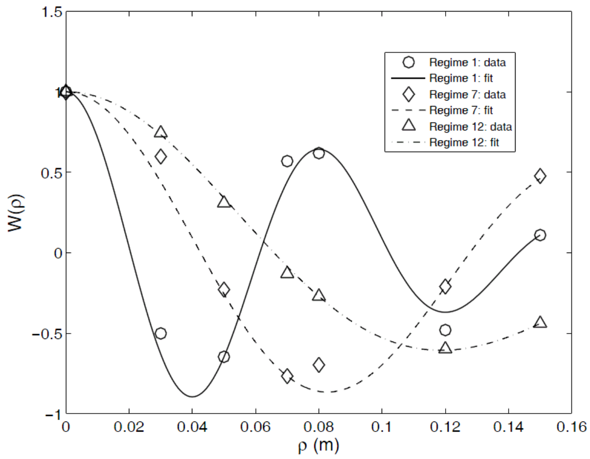

Fig. 1.4 Spatial correlation functions

The properties of this spatial correlation function appear to depend upon the flow properties such as the flow velocity and mean depth, and it may also infer hydraulic roughness. Future work will investigate the remote detection of physical bed roughness and sediment and pollutant transport characteristics.

The sensor is non-invasive and therefore low cost, low maintenance, and low power, offering a unique opportunity for accurate widespread monitoring.